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Indirect Limits on Higgs and SUSY Masses *

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Abstract

We review the current best fit values of Higgs boson masses in the Standard Model (SM) and its minimal supersymmetric extension (MSSM) obtained from existing experimental data. We also review the parameters space of the constrained MSSM (CMSSM) and the non-universal Higgs mass model (NUHM1) currently preferred by precision data. Following a Frequentist approach, the experimental data includes electroweak precision observables, B physics observables and the relic density of cold dark matter.

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Indirect Limits on Higgs and SUSY Masses

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We review the current best fit values of Higgs boson masses in the Standard Model (SM) and its minimal supersymmetric extension (MSSM) obtained from existing experimental data. We also review the parameters space of the constrained MSSM (CMSSM) and the non-universal Higgs mass model (NUHM1) currently preferred by precision data. Following a Frequentist approach, the experimental data includes electroweak precision observables, B physics observables and the relic density of cold dark matter.

1 Introduction

Identifying the mechanism of electroweak symmetry breaking will be one of the main goals of the LHC. Many possibilities have been studied in the literature, of which the most popular ones are the Higgs mechanism within the Standard Model (SM) [2] and within the Minimal Supersymmetric Standard Model (MSSM) [3].

Theories based on Supersymmetry (SUSY) [3] are widely considered as the theoretically most appealing extension of the SM. They are consistent with the approximate unification of the gauge coupling constants at the GUT scale and provide a way to cancel the quadratic divergences in the Higgs sector hence stabilizing the huge hierarchy between the GUT and the Fermi scales. Furthermore, in SUSY theories the breaking of the electroweak symmetry is naturally induced at the Fermi scale, and the lightest supersymmetric particle can be neutral, weakly interacting and absolutely stable, providing therefore a natural solution for the dark matter problem. SUSY predicts the existence of scalar partners $\tilde{f}_L, \tilde{f}_R$ to each SM chiral fermion, and spin–1/2 partners to the gauge bosons and to the scalar Higgs bosons. The Higgs sector of the Minimal Supersymmetric Standard Model (MSSM) with two scalar doublets accommodates five physical Higgs bosons. In lowest order these are the light and heavy $\mathcal{CP}$-even h and H, the $\mathcal{CP}$-odd A, and the charged Higgs bosons $H^\pm$. Higher-order contributions yield large corrections to the masses and couplings [4, 5]

So far, the direct search for SUSY particles has not been successful. One can only set lower bounds of $\mathcal{O}(100)$ GeV on their masses [6]. The search reach will be extended in various ways in the ongoing Run II at the upgraded Fermilab Tevatron [7]. The LHC [8, 9] and the e^+e^- International Linear Collider (ILC) [10] have very good prospects for exploring SUSY at the TeV scale, which is favored from naturalness arguments. From the interplay of both machines detailed information on many SUSY can be expected in this case [11].

Besides the direct detection of SUSY particles (and Higgs bosons), physics beyond the SM can also be probed by precision observables via the virtual effects of the additional particles. Observables (such as particle masses, mixing angles, asymmetries etc.) that can be predicted within a certain model and thus depend sensitively on the other model parameters constitute a test of the model on the quantum level. Various models predict different values of the same observable due to their different particle content and interactions. This permits to distinguish between, for instance, the SM and the MSSM via precision observables.

2 Higgs mass predictions in the SM

Within the SM the last unknown parameter, the mass of the Higgs boson $M_H^{\rm SM}$, can be predicted as described above. The fit is based on the electroweak precision observables (EWPO) measured at LEP and SLD and the Tevatron [12, 13, 14] and can include or exclude the direct searches performed at LEP [15] and at the Tevatron [16].

In Fig. 1 we show the result for the global fit to $M_H^{\rm SM}$ based on all EWPO. The "blue band plot" [13] shown on the left side of Fig. 1 excludes the direct searches, the right plot [17] includes these searches. In both plots $\Delta\chi^2$ is shown as a function of $M_H^{\rm SM}$. Excluding the direct searches yields[1]

$$M_H^{\rm SM} = 90^{+36}_{-29}\ {\rm GeV}\ , \quad M_H^{\rm SM} \le 163\ {\rm GeV}\ (95\%\ {\rm C.L.}), \tag{1}$$

still compatible with the direct LEP bound of [15]

$$M_H^{\rm SM} \ge 114.4\ {\rm GeV}\ (95\%\ {\rm C.L.}) \tag{2}$$

The theory (intrinsic) uncertainty in the SM calculations (as evaluated with `TOPAZ0` [18] and `ZFITTER` [19]) are represented by the thickness of the blue band. The width of the parabola itself, on the other hand, is determined by the experimental precision of the measurements of the EWPO and the SM input parameters.

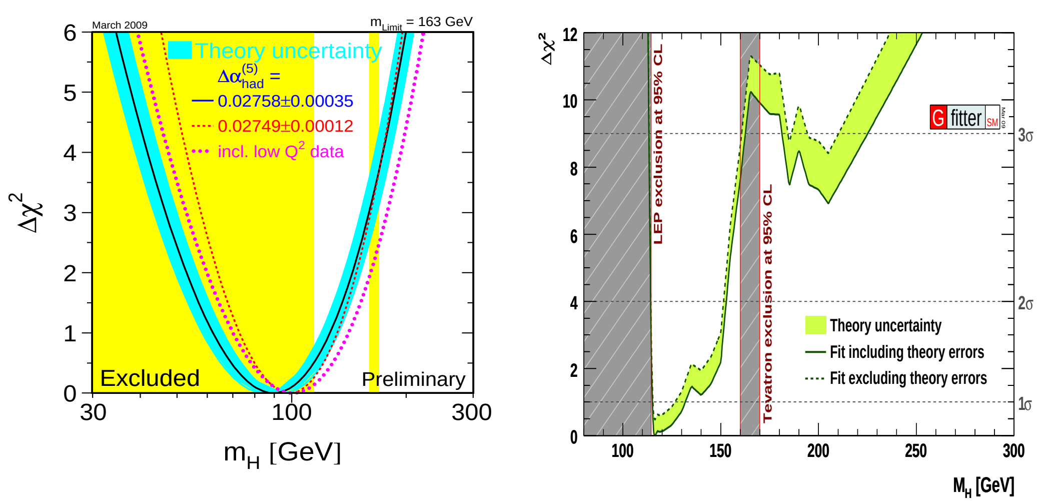

Figure 1: $\Delta\chi^2$ curve derived from all EWPO measured at LEP, SLD, CDF and D0, as a function of $M_H^{\rm SM}$, assuming the SM to be the correct theory of nature. The results of the direct searches are (not) included in the right [17] (left [13]) plot.

If the direct searches are included, shown in the right plot of Fig. 1, the preferred region changes to [17]

$$M_H^{\rm SM} = 116.4^{+18.3}_{-1.4}\ {\rm GeV}\ , \quad M_H^{\rm SM} \le 152\ {\rm GeV}\ (95\%\ {\rm C.L.}) \tag{3}$$

[1] A slightly tighter bound can be expected once all experimental results for M_W will have been combined.

3 Higgs mass predictions in the CMSSM

A fit as close as possible to the SM fit for $M_H^{\rm SM}$ (resulting in the left plot of Fig. 1) has been performed in Ref. [20] for the lightest Higgs boson in the Constrained MSSM (CMSSM). All EWPO as in the SM [13] (except Γ_W, which has a minor impact) were included, supplemented by the Cold Dark Matter constraint, the $(g-2)_\mu$ results and the BR$(b \to s\gamma)$ constraint (see Refs. [20, 21] for details and a complete list of references). Following a Frequentist approach, the χ^2 is minimized with respect to all CMSSM parameters for each point of this scan. Therefore, $\Delta\chi^2 = 1$ represents the 68% confidence level uncertainty on M_h. Since the direct Higgs boson search limit from LEP is not used in this scan the lower bound on M_h arises as a consequence of *indirect* constraints only, as in the SM fit.

In Fig. 2 [20] $\Delta\chi^2$ is shown as a function of M_h in the CMSSM. The area with $M_h \geq 127$ is theoretically inaccessible. There is a well defined minimum in the red band parabola, leading to a prediction of [20]

$$M_h^{\rm CMSSM} = 110^{+8}_{-10}\ ({\rm exp}) \pm 3\ ({\rm theo})\ {\rm GeV}, \tag{4}$$

where the first, asymmetric uncertainties are experimental and the second uncertainty is theoretical (from the unknown higher-order corrections to M_h [23, 24]). (An update using the latest m_t measurements is currently being prepared [25].) The fact that the minimum in Fig. 2 is sharply defined is a general consequence of the MSSM, where the neutral Higgs boson mass is not a free parameter. The theoretical upper bound $M_h \lesssim 135(127)$ GeV in the (C)MSSM explains the sharper rise of the $\Delta\chi^2$ at large M_h values and the asymmetric uncertainty. In the SM, $M_H^{\rm SM}$ is a free parameter and only enters (at leading order) logarithmically in the prediction of the precision observables. In the (C)MSSM this logarithmic dependence is still present, but in addition M_h depends on m_t and the SUSY parameters, mainly from the scalar top sector. The low-energy SUSY parameters in turn are all connected via RGEs to the GUT scale parameters. The sensitivity on M_h is therefore the combination of the indirect constraints on the four free CMSSM parameters and the fact that M_h is directly predicted in terms of these parameters.

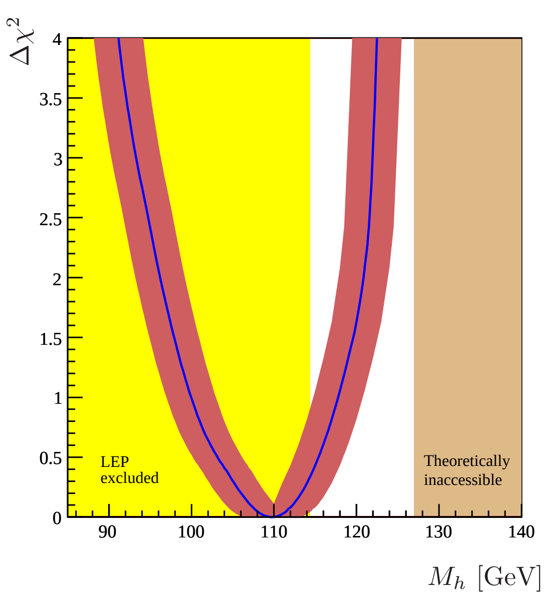

Figure 2: Scan of the lightest Higgs boson mass versus $\Delta\chi^2$ in the CMSSM [20] (using $m_t = 170.9 \pm 1.8$ GeV). The direct limit on M_h from LEP [15, 22] is not included. The red (dark gray) band represents the total theoretical uncertainty from unknown higher-order corrections.

4 SUSY mass predictions in the CMSSM and NUHM1

In a similar way to the CMSSM Higgs boson mass determination also the SUSY parameters themselves can be fitted [21]. Many analyses in this direction have been performed, see Ref. [21] for a list of references.

In Fig. 3 [21] we show the preferred regions in the CMSSM (left) and the non-universal Higgs mass model (NUHM1) (right) in the m_0-$m_{1/2}$ plane. The solid (dot-dashed/dashed) line shows the regions that can be covered at CMS with 1 fb^{-1}at 14 TeV (100 pb^{-1}at 14 TeV/50 pb^{-1}at 10 TeV) of *understood* data. It can be seen that the LHC has good chances to discover the CMSSM or NUHM1 with early data. The mass spectrum of the two models for the two best-fit points is shown in Fig. 4. If one of these two points were realized in nature the LHC and the ILC could observe many SUSY particles and measure their properties [8, 9, 10].

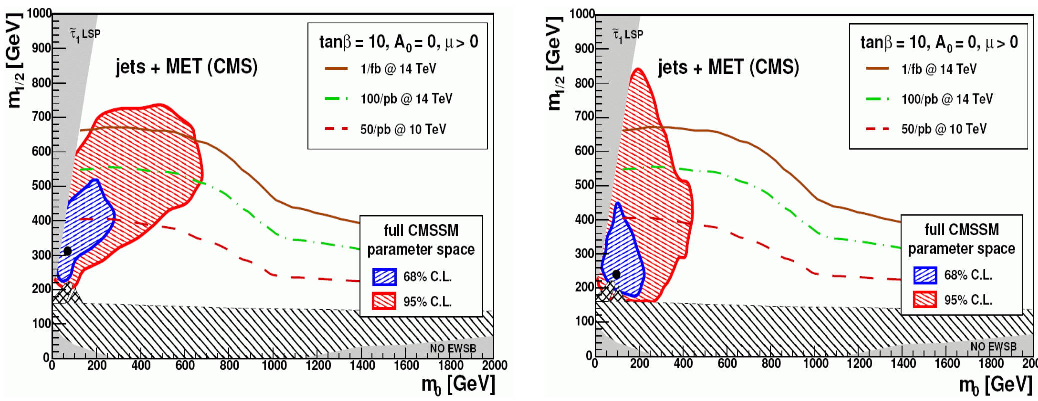

Figure 3: Areas in the m_0-$m_{1/2}$ planes preferred by current experimental data [21]; left: CMSSM, right: NUHM1.

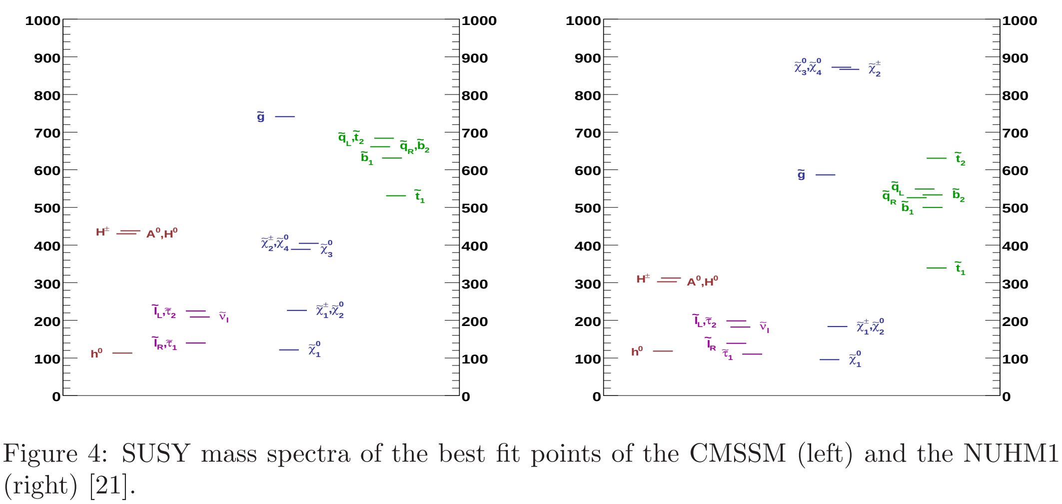

Figure 4: SUSY mass spectra of the best fit points of the CMSSM (left) and the NUHM1 (right) [21].

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